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# Corrosion Inhibitor for Cables in Post-Tensioned Bridges

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# Corrosion Inhibitor for Cables in Post-Tensioned Bridges

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# 1/INTRODUCTION

There has been some fear expressed regarding the possible corrosion of the cables or tendons used for post-tensioning bridges. If de-icing salts did penetrate through the concrete of the deck to the high points of the cable ducts over the columns and through the ducts, then corrosion could occur. To date, several inspections at these points have revealed no corrosion on the high tensile strength wires. It was suggested that if a corrosion inhibitor could be incorporated into the grout which fills the ducts, then no danger would result should the brine solutions penetrate to the wires.

There is a corrosion inhibitor currently available which is recommended for preventing the corrosion of rebars in concrete. This inhibitor is calcium nitrite and is marketed in Canada as a 30% solution under the name, "Darex Corrosion Inhibitor" (DCI). It was decided to test this inhibitor to determine if it would prevent salt-induced corrosion on high tensile strength wires embedded in grout; the wires would be both stressed and unstressed.

## 2/ EXPERIMENTAL

Four grout specimens were made. These specimens each contained post-tensioning wires. Two specimens (one inhibited and one uninhibited) had the wires unstressed, and two specimens (one inhibited and one uninhibited) had the wires stressed.

The grout mix was made up using Type 30, High Early Strength Cement at a 0.5 water-cement ratio (by mass). A water reducing agent was used at the rate of 4 mL/kg of cement. A separate batch was made for each specimen. The calcium nitrite was added to the batches for the inhibited specimens. Due to a misunderstanding, the inhibitor was added at a rate of 5% by weight based on the cement. The recommended dosage was 2 to 4%.

The four specimens were made, each 520 mm long, 300 mm wide, and 105 mm deep. The test wires were set 25 mm below the surface. The two specimens in which the wires were stressed, were made in steel forms so that the wires could be stressed against load cells. These steel forms were painted white with a corrosion-resistant paint* before the test specimens were cast in them. The finished specimens are shown in Figures 1 and 2.

Two types of wires were used in each specimen. They were:

| Wire Type | A | B |
|---|---|---|
| ASTM Grade | 270 | WA |
| Diameter, mm | 5.3 | 7.0 |
| Minimum Tensile Strength, MPa | 1690 | 1620 |

In the unstressed specimens, one wire of each type was used. In the stressed specimens, two Type A wires and one Type B wire were used. The Type B wire was placed between the two Type A wires.

*Tremclad corrosion paint, two coats, no primer necessary.

Prior to pouring the grout in the moulds, the wires were stressed. All four Type A wires were stressed to 690 MPa (100 000 psi). The Type B wire in the control (uninhibited) specimen was stressed to 565 MPa and the Type B wire in the inhibited specimen was stressed to 420 MPa. These two specimens could not be stressed to 690 MPa because the threads on the wire ends started to strip and the stressing had to be stopped at the values noted.

After pouring the grout, the specimens were cured for three days in the Moisture Room, then brought out into the laboratory for testing.

## 3/ TEST RESULTS

### 3.1/ Copper/Copper Sulphate Half-Cell Potentials

After the specimens were brought into the laboratory, half-cell potentials were read on each sample. The half-cell potential was measured by a $Cu/CuSO_4$ cell on the surface at three points on the surface over each wire in each specimen. Initially, the potentials were high and, as the grout dried out, the potentials began to drop. After about four weeks, the potentials reached a certain degree of constancy.

During this period, some very fine shrinkage cracks appeared on the surface of test specimens. After three weeks of relative equilibrium, 4% salt solutions were ponded on the specimens and they were kept under these conditions for more than two years. Once each week the solutions were removed from the surface of the specimens and half-cell readings were taken. The values obtained are shown in Figures 3 and 4.

In the figures, it can be seen that very soon after the salt solutions were ponded on the surface, the corrosion potential began to rise. In the unstressed specimens, the potentials rose very rapidly. In the uninhibited specimen, it passed the corrosion potential of 0.35 V within one week and rose to 0.55 V. In the inhibited specimen, the rise was much slower and took about two months to reach the corrosion potential. The potential of the inhibited specimen remained below that of the uninhibited specimen for about one year, then both seemed to level out at about 0.50 V.

In the stressed specimens, the potential in both the inhibited and the uninhibited rose rapidly to about 0.55 V and stayed there, with minor variations, throughout the test period of two and one-half years.

### 3.2/ Polarization Curves

After the specimens had been ponded for two years, polarization curves were run on the unstressed control and unstressed inhibited samples. These curves were run at a sweep rate of 400 mV/h. The curves are shown in Figure 5.

The corrosion current, $I_{corr}$, for the inhibited specimen was calculated to be 0.30 mA, and for the control specimen, to be 1.23 mA. This would indicate that there was some corrosion occurring in the inhibited specimen, but it was at a lower level than in the uninhibited control specimen.

### 3.3/ Examination of Test Samples

Before the specimens were broken, cores were taken from each. These cores were sliced and the chloride content was determined. The chloride profile of each specimen is shown in Figure 6. The chloride content of the cement used was 0.11% by weight.

After 30 months, the brine solutions were removed from the surface of the test specimens and the specimens were allowed to dry for one month. Then, the samples were broken open and the wires examined for corrosion. The following were the observations made at this time:

- **Control, Unstressed**

The specimen was broken with a hammer and the wires were examined. It was found that both the Type A and Type B wires showed considerable corrosion. The corrosion was heavy toward the ends of the wires, with very little corrosion at the centre. Some scaling was apparent at the ends. The corrosion was also heavier on the underside of the rod, rather than on the top. Figure 7 shows the corrosion on these wires.

- **Inhibited, Unstressed**

The specimen was broken with a hammer and examined. Corrosion was apparent on both the Type A and Type B wires; it was heaviest at the ends and less at the centre, with the heaviest corrosion on the underside of the rod. The corrosion was, however, much less than in the control sample. Figure 8 illustrates this corrosion.

- **Control, Stressed**

The tension on the wires was removed and then the sample was broken. It was found that the centre Type B wire was corroded, top and bottom, over its entire length. One Type A wire was almost clear of corrosion, while the other Type A wire had some corrosion at one end and very little at

the other end. Again, the corrosion was heaviest on the underside of the rod. Figure 9 shows the corrosion on these three wires.

**• Inhibited, Stressed**

The centre Type B wire was virtually free of corrosion, and one Type A wire was also clear of corrosion, while the other had some corrosion at the ends and a small amount at the centre. Figure 10 shows the corrosion on the three wires.

## 4/ DISCUSSION

The examination of the wires in the four test specimens indicated that some inhibition had resulted from the use of calcium nitrite. The corrosion was considerably worse in the uninhibited samples. The corrosion which occurred in the four specimens was not evenly distributed across the wires. This can be seen from the results of the stressed specimens. In each of the two, one Type A wire showed very little corrosion, while the other showed considerably more corrosion.

The chloride profiles of the specimens showed that the chloride had penetrated through to the bottom of the samples. The very rapid increase in corrosion potential shown in Figures 3 and 4 after the addition of the brine solution, indicated rapid penetration of the solution to the wires. There was definitely less corrosion on the Type B wires in the inhibited specimens. There was some doubt if the Type A wires in the stressed specimens showed any difference between inhibited and the uninhibited specimens.

The calcium nitrite did not inhibit corrosion of the steel frame used for the stressed specimens. These frames had been painted with a rust-resistant paint. Figures 11 and 12 show the two frames, and the corrosion of the end plate of the inhibited specimen frame is just as heavy as that of the uninhibited specimen's frame.

The polarization curves run on the unstressed specimens to determine the corrosion current indicate that the corrosion rate was lower in the inhibited specimen. The copper/copper sulphate half-cell used in the measurement, was placed centrally over the Type B wire. The other wire, Type A, was used as the auxiliary electrode.

## 5/ CONCLUSIONS

It would appear from these results that some corrosion reduction was afforded by the use of calcium nitrite; however, the reduction was not great. Based on observation of the test wires, it was estimated that the reduction would be about 50%. There did appear to be a greater amount of corrosion on the stressed wires than on the unstressed wires. It must be pointed out, however, that 5% inhibitor was used instead of a recommended dosage of 2 to 4%

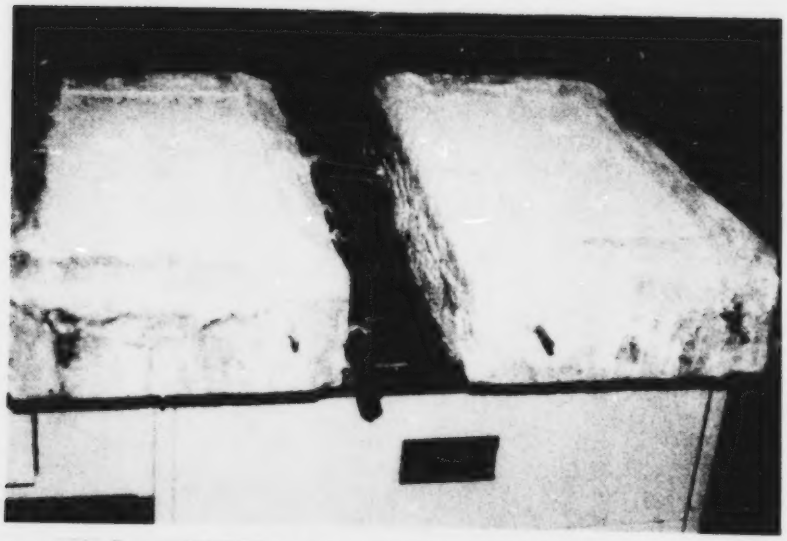

Figure 1/ Unstressed Grout Specimens

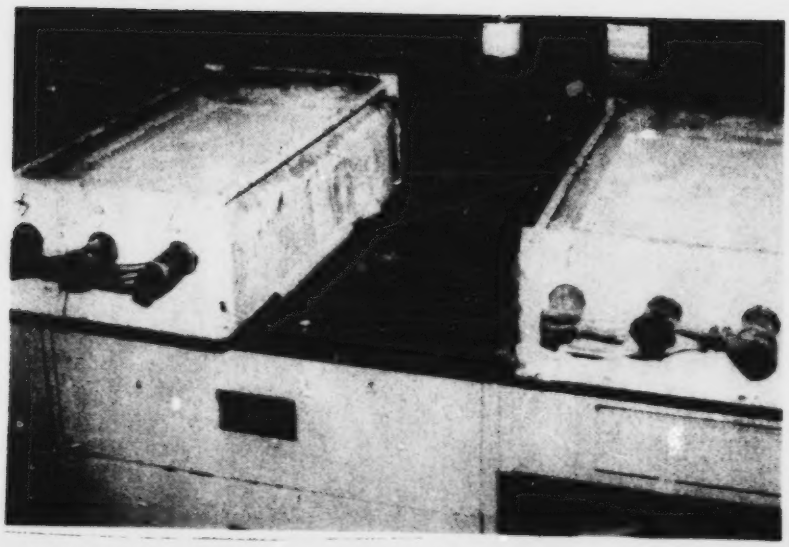

Figure 2/ Stressed Grout Specimens

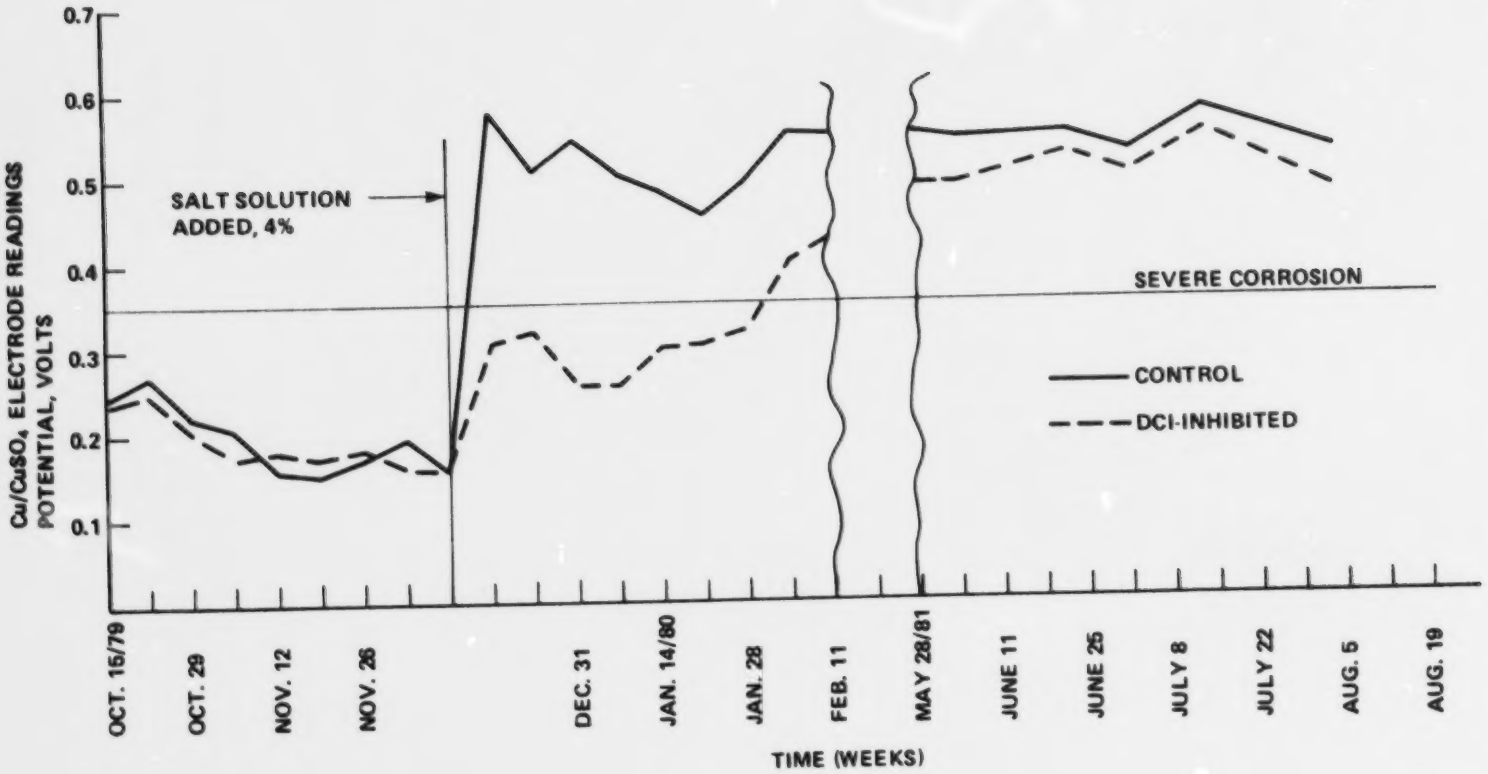


Figure 3/ Corrosion Potential vs. Time, Unstressed Specimens

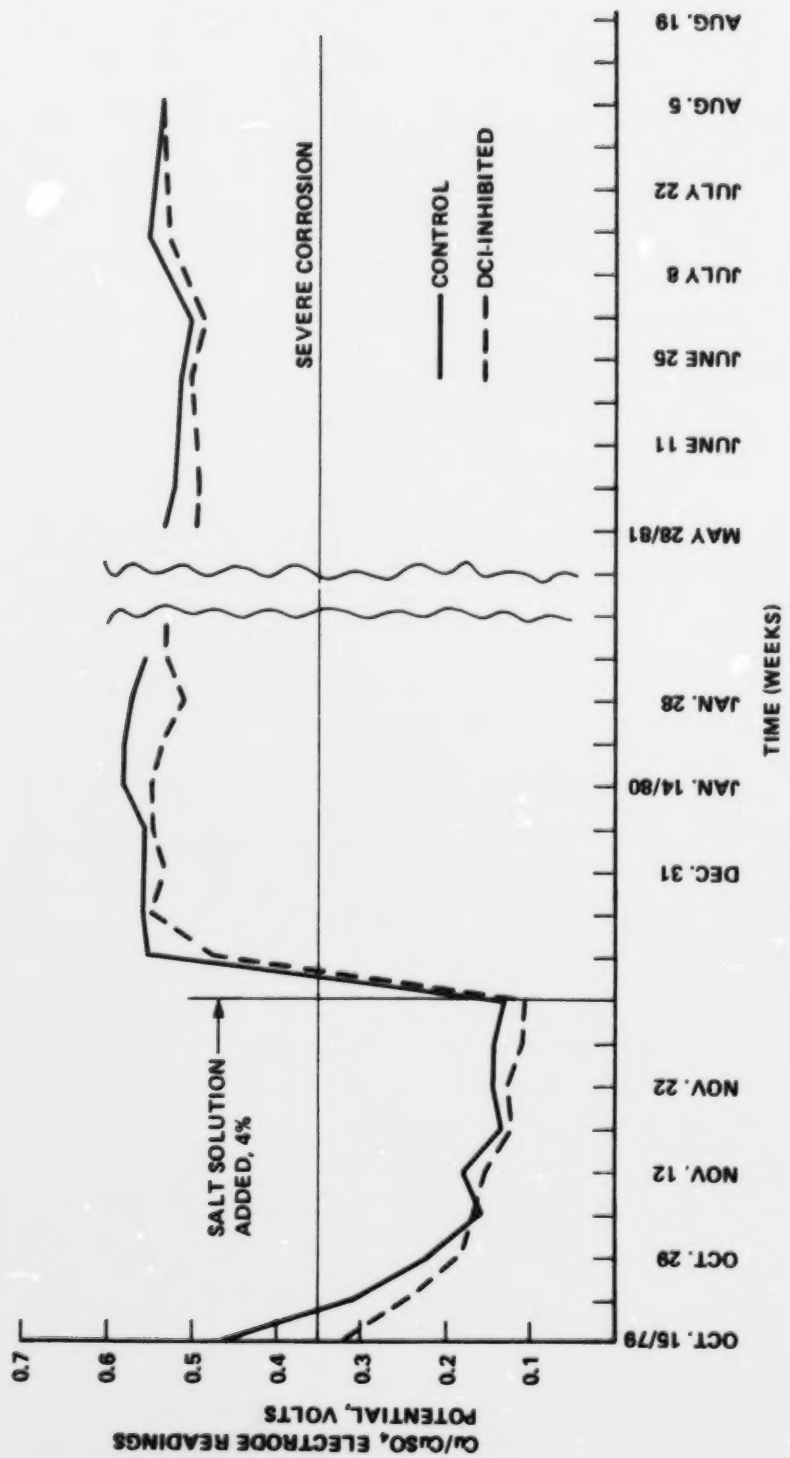


Figure 4/ Corrosion Potential vs. Time, Stressed Specimens

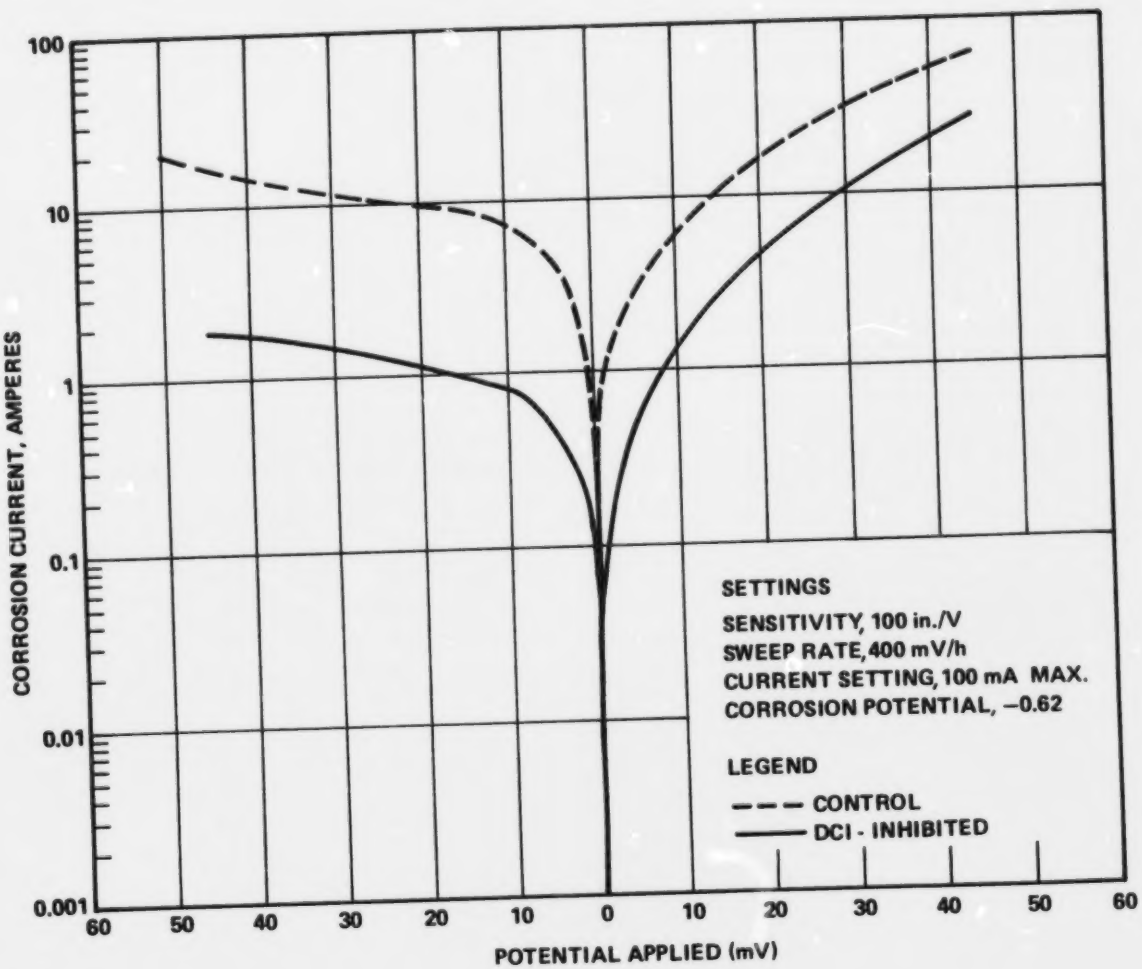


Figure 5/ Polarization Curves for Control and Inhibited Unstressed Specimens

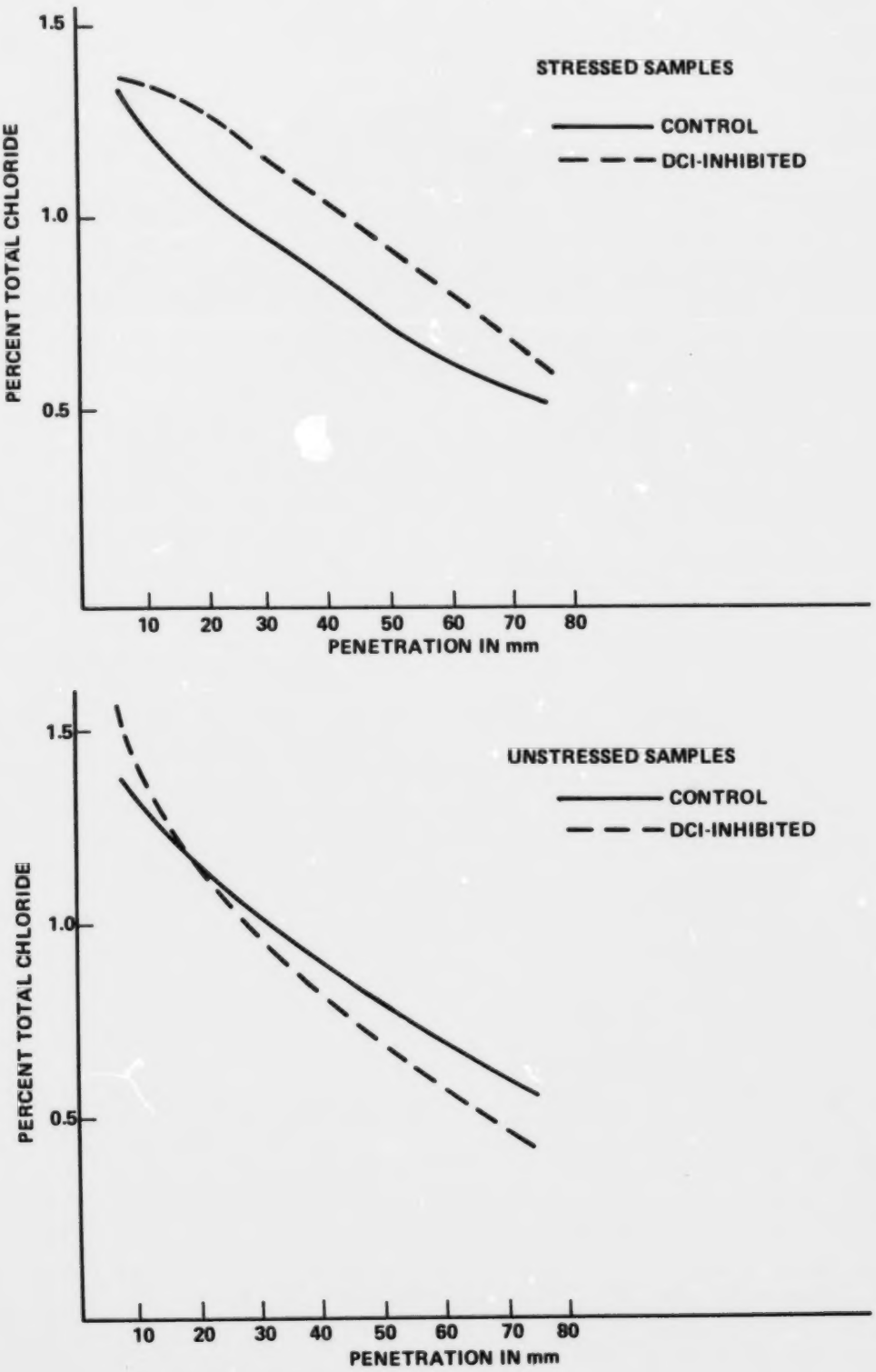


**Figure 6/ Chloride Penetration into Grout after 30 Months**

Figure 7/ Corrosion on Unstressed, Uninhibited Wires

Figure 8/ Corrosion on Unstressed DCI-Inhibited Wires

Figure 9/ Corrosion on Stressed Uninhibited Wires in Frame

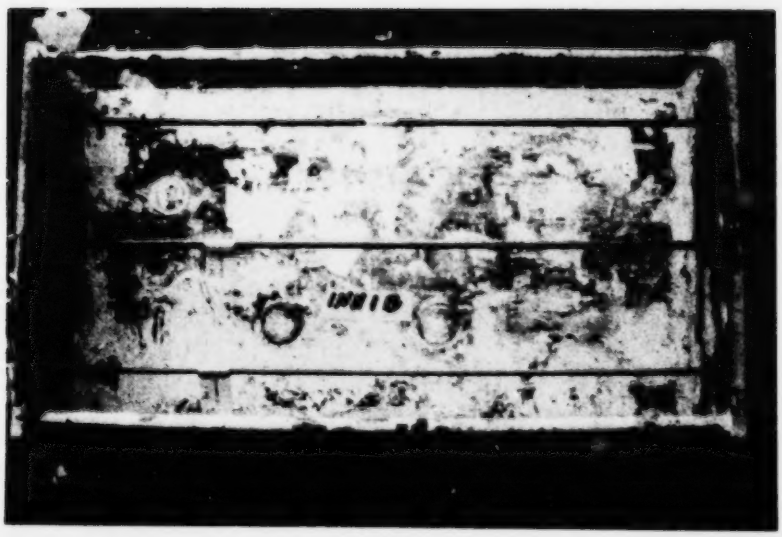

Figure 10/ Corrosion on Stressed DCI-Inhibited Wires in Frame

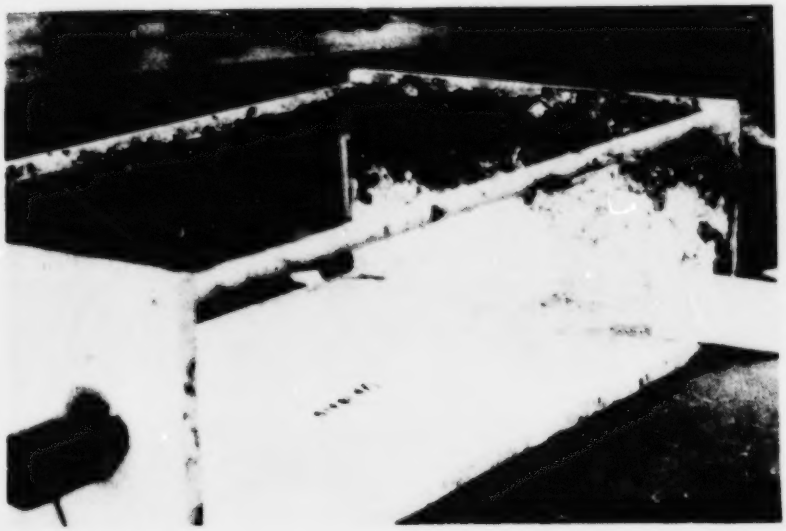

Figure 11/ Corrosion on Frame of Uninhibited Stressed Specimen

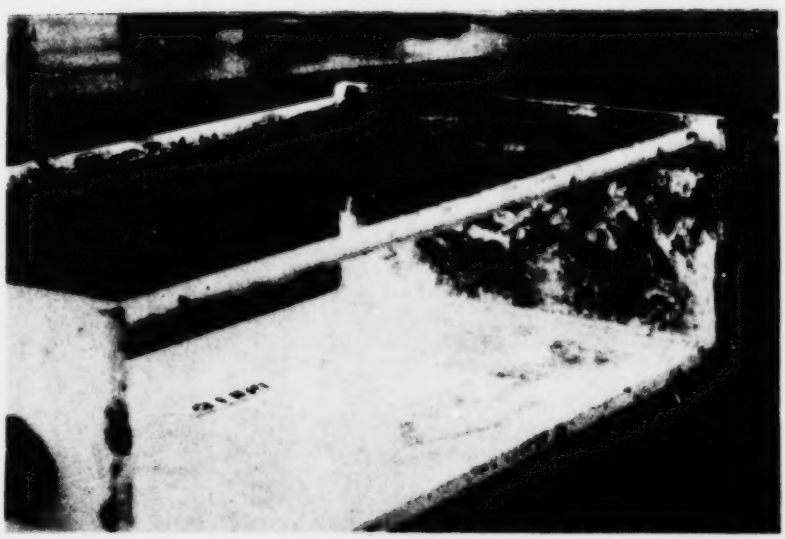

Figure 12/ Corrosion on Frame of DCI-Inhibited Stressed Specimen